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DESCRIPTION

CONTINUOUS VACUUM CARBURIZING PROCESS AND APPARATUS FOR METAL WIRE, METAL STRIP OR METAL PIPE

TECHNICAL FIELD

[0001]

The present invention generally relates to a process and apparatus for manufacturing metallic material which has superior toughness and wear resistance. More particularly, the invention relates to a continuous vacuum carburizing process for metal wires, metal strips, or metal pipes and an apparatus for carrying out the process.

BACKGROUND ART

[0002]

Most of steels used as wear resistant material have a high carbon content and low cold-workability. Thus, in a cold drawing process of a steel wire, stress relief annealing has to be performed frequently to reduce hardness of the work-hardened wire. Such frequent stress relief annealing increases process lead time.

Besides, in the case of ingot material, during its solidification process, large primary carbides are produced in the material. The large carbides are not destroyed completely and remain even

after subsequent hot working or cold working. Consequently, when this material is used as wires, the large carbides serves as stress concentration sources, causing chips or breakage.

[0003]

To deal with the above problems, Japanese Patent No. 3053605 discloses a technique for working low-carbon steel stock with a limited ingredient balance into sheet or thin wire shapes and subsequently carburizing them to the center. This technique produces, with high manufacturing efficiency, metallic material in which hard carbides are distributed finely and uniformly to provide superior toughness and wear resistance. However, the patent makes no mention of problems involved in carburizing wires or flat strips.

[0004]

JP-A-6-192814 and JP-A-7-126829 disclose methods for carburizing metal strips continuously. However, they neither disclose nor suggest anything about carburizing material uniformly to its center as discussed by the patent mentioned above.

[0005]

As concerns carburizing depth when carburizing steels, known techniques for carburizing the objects with substantially semi-infinite carburizing depth include gas carburizing which involves carburizing the objects by adjusting the carbon potential of carburizing gas and vacuum

carburizing which involves carburizing the objects under reduced pressure.

In the case of small diameter material such as wire rods, since the carburizing depth coincides with the radius of the material, if the material has application of a carburizing process (hereinafter referred to as batch processing), such as described in Japanese Patent No. 3053605, which involves adding a carburizing medium after putting a workpiece in a furnace, variations in carburizing conditions are reflected directly in the amount of carbon in the inner section of the material.

[0006]

In addition, gas carburizing, in particular, tends to cause problems that carbon penetration increases due to adhesion of soot to surface portions of the material, resulting in coarse carbides, that which surface defects occur due to surface oxidation, and that carbon becomes insufficient and predetermined heat-treated hardness is not obtained.

In batch processing of material having a small wire diameter, in particular, predetermined carbon penetration is reached at an initial stage of introducing carburizing atmosphere gas and its control is very difficult. Furthermore, affection of surface defects cannot be ignored because of a large specific surface area.

DISCLOSURE OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

[0007]

The present invention, in view of the problems described above, has an object to provide a carburizing process for metal wires, metal strips or metal pipes which has far less variation in the amount of carburization in the material and is free of surface oxidation or sooting.

Another object of the invention is to provide a carburizing apparatus for effectively carrying out the above process.

MEANS FOR SOLVING THE PROBLEM

[0008]

To achieve the above first object, according to the invention, there is provided a continuous vacuum carburizing process comprising, under a reduced pressure of 5 kPa or less, forming at least one carburizing atmosphere in which pressure and gas composition are constant with one of chain saturated hydrocarbon, chain unsaturated hydrocarbon gas and cyclic hydrocarbon used as a carburizing medium, activating carbon in the carburizing atmosphere, and passing one material of a metal wire, a metal strip and a metal pipe, which has a carbon content equal to or less than a desired carbon content, continuously through the carburizing atmosphere and thereby

carburizing the material.

[0009]

To effectively carry out the above process, a continuous vacuum carburizing apparatus according to another aspect of the invention comprises a furnace core portion formed to enclose a fixed space through which one material of a metal wire, a metal strip and a metal pipe is passed continuously, means for supplying as a carburizing medium one of chain saturated hydrocarbon, chain unsaturated hydrocarbon gas and cyclic hydrocarbon to the furnace core portion under a reduced pressure of 5 kPa or less and discharging the carburizing medium to form at least one carburizing atmosphere in which pressure and gas composition are constant, and means for activating carbon of the carburizing medium within the furnace core portion.

[0010]

With the above construction, the carburizing atmosphere is in the reduced pressure condition in which no oxide layer is formed on a material surface and the carburizing medium causes no soot on the material surfaces. Also, the carburizing atmosphere has constant pressure and constant gas composition in a condition that the carbon is activated. The material to be carburized is moved through this atmosphere, and it is possible to perform appropriate carburization with less variation in the amount of carburization. The material can be carburized continuously, making it

possible to process a large amount of material efficiently.

[0011]

Preferably, the above continuous vacuum carburizing process further comprises heating a fixed area, through which the material passes following the carburizing atmosphere and in which the carburizing medium does not exist, and causing the carbon carburized in the material to be diffused into inner sections of the material.

In this fixed area, a carrier gas atmosphere may be formed by supplying and discharging carrier gas.

For this end, the continuous vacuum carburizing apparatus preferably further comprises means for supplying and discharging a carrier gas to/from the furnace core portion to form, on a downstream side of the carburizing atmosphere with respect to a travel direction of the material, at least carrier gas atmosphere without the carburizing medium.

By providing such an area, it is possible to diffuse a desired amount of carbon reliably into the material.

[0012]

Preferably, the activation of carbon is performed by heating the carburizing atmosphere to 850°C to 1050°C. The carburizing medium gas is decomposed by the heating and produces active carbon. This temperature range facilitates reaction of the

carburizing medium gas and diffusion of the carbon which penetrates into the material while inhibiting grain growth in the material.

The activation of carbon may be performed by bringing the carbon into a plasma state in addition to the heating of the carburizing atmosphere. For this end, the continuous vacuum carburizing apparatus preferably comprises an electric heater for heating the furnace core portion to 400°C to 1050°C and a discharger for causing glow discharge. By accelerating carbon ions, carburization of the material can be performed more efficiently.

[0013]

The continuous vacuum carburizing apparatus may further comprise lowering pressure in a surrounding area of the carburizing atmosphere than the pressure of the carburizing atmosphere.

The above apparatus preferably further comprises a feeding/taking-up mechanism for passing the material through the furnace core portion, and a vacuum container for receiving the furnace core portion, the supply/discharge means and the heating means, which is kept in its inside at a lower pressure than pressure in the furnace core portion.

By keeping the surrounding area at a lower pressure, the gas degraded as a result of reaction is discharged out of the carburizing atmosphere quickly, and contaminated gas is prevented from flowing into the

carburizing atmosphere from the outside. This makes it possible to stably keep the gas composition in the carburizing atmosphere in desirable condition.

[0014]

In the continuous vacuum carburizing process, the passing of the material through the carburizing atmosphere and then through the fixed area having no carburizing medium may be repeated multiple times.

To carry out the vacuum carburizing process, in the continuous vacuum carburizing apparatus, the furnace core portion and the supply/discharge means are preferably adapted to form a plurality of carburizing atmospheres in the furnace core portion.

In some ferrous material, there is a fear that a coarse network of carbide crystals will be deposited on a surface if the entire amount of carbon required to carburize the material to its center is introduced into the material at once. Pulse carburizing which repeats a short cycle of carburizing and diffusion multiple times is effective in this situation. By forming the plurality of carburizing atmospheres in the furnace core portion, it is possible to carry out such pulse carburizing.

[0015]

Preferably carburizing is performed until the material reaches or exceeds the desired carbon content.

This process makes it possible to use material with a low carbon content, cold-work it into a

desired shape and then carburize the material appropriately, thereby facilitating the working of the material and giving desired strength to the material.

[0016]

The material to be carburized may have a diameter of 0.02 mm to 3 mm in case of the metal wire, a thickness or width of 0.02 mm to 3 mm in case of the metal strip and a wall thickness of 0.02 mm to 3 mm in case of the metal pipe.

The continuous vacuum carburizing process according to the invention, by continuously feeding the material into the fixed carburizing atmosphere, causes far less variation in carburizing even in the case of a thin material which has a thickness almost equal to a carburizing depth.

The carburization may be made to the center of the cross section of the material or only to its surface layer.

[0017]

Material to be carburized may be carbon steel for machine construction, alloy steel for machine construction, tool steel, spring steel, or stainless steel.

Alternatively, the material to be carburized may be a nickel alloy or cobalt alloy containing one or more carbide-forming elements out of boron, titanium, vanadium, chromium, zirconium, niobium, molybdenum, hafnium, tantalum, and tungsten.

Alternatively, the material to be carburized may be a metal or alloy having as main constituent one carbide-forming element of boron, titanium, vanadium, chromium, zirconium, niobium, molybdenum, hafnium, tantalum, and tungsten.

ADVANTAGES OF THE INVENTION

[0018]

As described above, according to the continuous vacuum carburizing method and apparatus of the invention, by moving material through the fixed carburizing atmosphere, it is possible to perform appropriate carburizing with far less variation in the amount of carburization. In particular, when material has a small diameter or thickness, it has conventionally encountered problems that desired hardness is not obtained after heat treatment and that coarse carbide is generated. The process and apparatus of the invention can eliminate these problems.

BEST MODE FOR CARRYING OUT THE INVENTION

[0019]

A continuous vacuum carburizing process and apparatus of the invention will be described in detail based on the embodiments shown in the accompanying drawings.

FIG. 1 schematically shows a manufacturing process of a tool steel wire with the use of the

continuous vacuum carburizing apparatus according to the embodiment of the invention. The process uses wire rods of low-carbon alloy steel as material and includes a continuous wire drawing step, a continuous stress relief annealing step, a carbide dispersion carburizing step, and a quenching/tempering step.

[0020]

In the continuous wire drawing step, the wire rod is fed continuously from a supply side to a take-up side and drawn efficiently through a plurality of dies. The wire rod having a diameter of 5 to 8 mm is moved through the dies 5 to 20 times and its cross-sectional area is reduced to 1/5 or less.

The wire rod hardened in this step is then transferred to the continuous stress relief annealing step, and the wire rod is heated to a predetermined temperature in a continuous stress relief furnace and reduced in hardness. Subsequently, the wire rod is returned to the continuous wire drawing step and it is drawn again until its cross-sectional area is reduced to 1/5 or less. The wire drawing and continuous stress relief are repeated until the wire rod reaches a predetermined wire diameter.

[0021]

The wire rod, when the wire drawing has been completed to the predetermined wire diameter, is transferred to the carbide dispersion carburizing step. In this step, the continuous vacuum carburizing

apparatus of the invention provides carburization treatment on the wire rod into its inner section.

The wire rod completed of carburization is transferred to the quenching/tempering step. In this step, the wire rod is quenched and tempered continuously in a continuous quenching/tempering furnace and consequently attains a predetermined hardness.

[0022]

FIG. 2 shows the continuous vacuum carburizing apparatus or furnace according to this embodiment in detail.

The continuous vacuum carburizing furnace has an elongate vacuum container 9, a plurality of furnace core tubes 1, 11, and 12 (three in the illustrated example) placed in the vacuum container along a longitudinal direction thereof, and a feeding/taking-up mechanism for passing the steel wire 7, which has been drawn to the predetermined diameter, through a furnace core portion formed of the furnace core tubes.

[0023]

Each core tube 1, 11, or 12 has an elongate shape with both ends open and is equipped with a carburizing gas inlet pipe 2, a carrier gas inlet pipe 3, and a pair of exhaust pipes 4. Furthermore, each furnace core tube is equipped with an electric heater 10 along its longitudinal direction.

The inlet pipes 2, 3 and the exhaust pipes 4,

4 extend through the vacuum container 9 and are connected to the furnace core tube to introduce carburizing gas and carrier gas into the furnace core tube from outside the vacuum container and discharge them outside the vacuum container.

[0024]

The exhaust pipes 4, 4 are arranged on both sides of the carburizing gas inlet pipe 2 with regard to the longitudinal direction of the furnace core tube. The inside of the furnace core tube between the exhaust pipes constitutes a carburizing portion 5 occupied by the carburizing gas. The carrier gas inlet pipe 3 is arranged on the downstream side of the carburizing gas inlet pipe 2 and the exhaust pipes 4, 4 with regard to the travel direction of the steel wire 7. That inside of the furnace core tube on this downstream side constitutes a diffusing portion 6 filled with the carrier gas.

By the way, although in FIG. 2 only the furnace core tube 1 is given reference numerals 2 to 6 and 10, the core tubes 11, 12 have similar construction.

[0025]

The vacuum container 9 has an exhaust pipe 8 equipped with an evacuation valve (not shown) and can evacuate the inside of the container.

The feeding/taking-up mechanism includes a feed bobbin 13 and a take-up bobbin 14, which are

installed on both sides of the furnace core tubes 1, 11, and 12 in the vacuum container. The bobbins 13, 14 are rotatively driven, reel out the steel wire 7 wound around the bobbin 13, pass it through the furnace core tubes 1, 11, and 12 and take up it on the take-up bobbin 14.

Incidentally, the feeding/taking-up mechanism may be installed outside the vacuum container. In that case, it is preferable that a differential exhaust mechanism is provided to prevent air from entering the vacuum container along with the travel of the steel wire 7.

[0026]

The continuous vacuum carburizing furnace operates as follows according to an embodiment of the process of the invention.

First, the steel wire 7 is led through the furnace core tubes 1, 11, and 12 from the feed bobbin 13 and connected to the take-up bobbin 14. Then, the entire vacuum container 9 is evacuated sufficiently through the exhaust pipe 8. When the inside of the vacuum container reaches a predetermined degree of vacuum below 10 Pa, electric current is delivered to the electric heater 10 and the furnace core tubes 1, 11, and 12 are heated to a predetermined temperature of between 850°C and 1050°C.

[0027]

Then, the carburizing gas such as ethylene

and the carrier gas such as nitrogen or argon are introduced into the furnace core tubes 1, 11, and 12 through the carburizing gas inlet pipes 2 and the carrier gas inlet pipes 3. At the same time, the vacuum in the vacuum container 9 is controlled through adjustment of the evacuation valve of the exhaust pipe 8 and the pressure in the furnace core tubes 1, 11, and 12 is restored to 5 kPa or lower, preferably to 1 to 3 kPa.

After the adjustment of the atmosphere, the steel wire 7 is passed through the furnace core tubes 1, 11, and 12 and taken up on the take-up bobbin 14 by operation of the feeding/taking-up mechanism. When a required amount of steel wire is obtained, the furnace is cooled, the vacuum of the vacuum container is removed, and the steel wire 7 is taken out of the furnace together with the bobbin. Thus, the steel wire processed to the predetermined diameter and carburized is obtained.

[0028]

The carburizing medium gas is introduced and discharged continuously into/from each furnace core tube heated to 850°C to 1050°C via the carburizing gas inlet pipe 2 and the exhaust pipes 4, 4, and it functions as the carburizing atmosphere which has a constant pressure and constant constituent gases and is capable of vacuum carburizing. This atmosphere carburizes the steel wire 7 passing through it. Then,

the carburized steel wire 7 passes through the heated diffusing portion 6 of each core tube. The diffusing portion has no gas serving as a carburizing medium, and the carbon carburized from the surfaces of the steel wire 7 diffuses into the inner section of the alloy.

The carburized portion may be limited to regions near the surface, or the entire material may be carburized to its center.

[0029]

The continuous vacuum carburizing process of the invention is performed under a reduced pressure of 5 kPa or less and uses chain saturated hydrocarbon, chain unsaturated hydrocarbon gas, or cyclic hydrocarbon as the carburizing medium. This is because at a pressure higher than 5 kPa, soot would be produced on the surface of the treated material, disabling proper carburizing. Also, the reason for the carburizing atmosphere with the reduced pressure is that carburizing performed under normal pressure would produce an oxide layer of 5 to 10 μm on the surface of the treated material. This defect will have large influence especially on small-diameter wire rods with large specific surface areas.

[0030]

The above-mentioned heating temperature condition of the carburizing atmosphere is because at 850°C or below, the gas serving as the carburizing medium (except special gases such as acetylene) does

not start reaction for forming cementite on the material surface, and consequently the material is not carburized. Also, the diffusion rate of carbon in steel is low at 850°C or below, making carburizing/diffusion operations inefficient. On the other hand, the upper limit of 1050°C is because at temperatures above 1050°C, steel wire undergoes marked grain growth, degrading its mechanical properties.

[0031]

The material to be treated by the continuous vacuum carburizing process of the invention is preferably 0.02 mm to 3 mm in diameter in the case of wire rods, for example. Material below 0.02 mm is difficult to control carburizing depth. With diameters above 3 mm, as it takes a long time to carburize the material to its center and variation in the time required to introduce gas have less influence, there is no necessity of specifically using the process of to the invention.

Nevertheless, the process of the invention is of course effective for the case of carburizing only surface layers of material at a predetermined density regardless of the size of the material.

[0032]

Although in the above embodiment, the carbon in the carburizing medium gas is activated by heating the furnace core tubes 1, 11, and 12, plasma may be used in addition to this activation.

FIG. 3 shows the essential part of the continuous vacuum carburizing apparatus according to another embodiment which performs such vacuum plasma carburizing. The apparatus may have the same or similar components as the embodiment of FIG. 2 except a portion for performing the generation of plasma. The same or similar components are denoted with the same reference numerals, and description thereof will be omitted.

[0033]

The continuous vacuum carburizing apparatus of this embodiment has a discharger 15 in addition to the apparatus construction of FIG. 2. The discharger 15 is electrically connected with the steel wire 7 via the furnace core tube 1 and the bobbin 13. During operation of the apparatus, the discharger 15 applies voltage between the furnace core tube 1 as an anode and the steel wire 7 as a cathode. This produces glow discharge in the furnace core tube 1 and makes the introduced carburizing medium gas into plasma. In addition, the electric heater 10 heats the furnace core tube 1 to 400°C to 1050°C.

The carbon in the carburizing medium gas is ionized and carbon ions adhere to the surfaces of the steel wire 7 effectively. In this way, the apparatus of the embodiment facilitates the carburizing of the steel wire 7 by converting the carburizing medium gas into plasma.

[0034]

FIG. 4A shows the gas inlet pipes 2, 3 and the exhaust pipes 4 of the continuous vacuum carburizing apparatus of FIG. 2 in an enlarged scale. The pipe layout in FIG. 4A is intended to form the carburizing gas atmosphere or carburizing portion 5 only in the shaded portion of each furnace core tube and to form an adjacent area on the right side in the figure as the diffusing portion 6 in which no carburizing medium gas exists. Specifically, the carburizing medium gas and the carrier gas, which are introduced into the furnace core tube simultaneously, tend to mix with each other in the furnace core tube. By disposing the exhaust pipe 4 between the carburizing gas inlet pipe 2 and the carrier gas inlet pipe 3, and by evacuating the furnace core tube from between the two gases independently, it is possible to prevent the carburizing gas from entering the right side of the furnace core tube.

[0035]

The introduction and discharge of the carburizing medium into/from the furnace core tube is intended to keep the carburizing medium in the furnace core tube at appropriate pressure and in appropriate atmosphere. The gas serving as the carburizing medium exists between the introduction site and the discharge site of the carburizing gas. To prevent the gas from leaking into the diffusing portion, a carrier gas inlet

pipe for blocking may be installed near a border with the diffusing portion.

Alternatively, the furnace core tube may be divided between the carburizing portion and diffusing portion to let the carburizing gas introduced into the carburizing portion escape into the vacuum container, thereby preventing the carburizing gas from leaking into the diffusing portion. In any case, it is important to maintain the carburizing gas atmosphere in the carburizing portion, and the atmosphere free of a carburizing medium in the diffusing portion.

[0036]

FIGS. 4B and 4C show modifications of the layout in FIG. 4A, intended to prevent leakage of the carburizing gas to the diffusing portion.

In the example in FIG. 4B, carrier gas inlet pipes 31 to 33 and exhaust pipes 41, 42 are installed additionally to more reliably prevent the carburizing gas from entering an area on the right side of the furnace core tube.

In the example in FIG. 4C, a furnace core tube for carburizing area and a furnace core tube for diffusing area are provided completely separately. In this case, the carburizing gas and the carrier gas escape into the vacuum container from their respective furnace core tubes, and thus there is no need to discharge them from the furnace core tubes directly.

[0037]

Wire rods were produced by way of trial from carbon steel for machine construction, alloy steel for machine construction, tool steel, spring steel, and stainless steel by the manufacturing process described above. Results of the trial are shown in Table 1. The trial products were by wire-drawing rolled coils of the various steel materials and then by carburizing them with the process of the invention or with a conventional batch process. The amounts of carbon were measured at six spots after carburizing to evaluate variations in the carbon amount, and Table 1 shows the variations.

In table 1, trial product Nos. 1 to 9 are tool steel wire rods, trial product Nos. 10 to 15 are stainless steel wire rods, trial product Nos. 16 to 17 are carbon steel wire rods, trial product Nos. 18 to 19 are alloy steel wire rods, trial product Nos. 20 to 21 are spring steel wire rods.

[0038]

[Table 1]

No	Chemical composition of rolled coil (wt.%)							Manufacturing method	
	C	Cr	W	Mo	V	Co	Fe	Adjustment of carbon content	Carburizing process
1	0.20	3.9	6.1	4.9	1.9		The rest	Carburizing after drawing	Process of Invention
2									Conventional process
3	0.90	3.9	6.0	4.8	2.0		The rest	No adjustment of Ingot	
4	0.20	3.9	6.1	4.9	1.9		The rest	Carburizing after drawing	Process of Invention
5									Conventional process
6	0.89	4.0	6.1	4.9	1.9		The rest	No adjustment of Ingot	
7	0.35	4.0	6.3	5.1	2.8	8.0	The rest	Carburizing after drawing	Process of Invention
8									Conventional process
9	1.25	4.0	6.2	5.2	2.7	7.9	The rest	No adjustment of Ingot	
10	0.25	12.5		1.0	0.3		The rest	Carburizing after drawing	Process of Invention
11									Conventional process
12	0.90	16.3		0.5			The rest	Carburizing after drawing	Process of Invention
13									Conventional process
14	0.30	13.5					The rest	Carburizing after drawing	Process of Invention
15									Conventional process
16	0.05						The rest	Carburizing after drawing	Process of Invention
17									Conventional process
18	0.04	1.0					The rest	Carburizing after drawing	Process of Invention
19									Conventional process
20	0.05	0.9			0.2		The rest	Carburizing after drawing	Process of Invention
21									Conventional process

- to be continued -

- continued -

No	Wire diameter mm	Carburizing temperature °C	Carburizing time (min.)	Diffusion temperature °C	Diffusion time (min.)	C% after carburizing 1	2	3	4	5	6	Results
1	0.1	950	0.27	1000	1.5	0.92	0.92	0.93	0.92	0.93	0.93	FIG.4
2						0.82	0.25	1.32	2.20	1.01	0.90	
3												
4	3.0	1030	10.00	1040	90.0	0.95	0.95	0.95	0.95	0.96	0.95	FIG.5
5						0.95	0.93	0.96	0.95	0.93	0.93	
6												
7	0.2	950	0.58	1020	3.0	1.24	1.26	1.26	1.25	1.26	1.26	FIG.6
8						1.33	1.58	0.10	0.25	1.45	0.75	
9												
10	0.8	1000	3.00	900	12.0	1.55	1.54	1.53	1.53	1.54	1.54	
11						1.00	1.20	0.50	0.87	0.76	1.35	
12	0.2	900	0.85	850	3.0	1.45	1.45	1.47	1.45	1.45	1.45	
13						1.24	1.36	1.04	1.25	1.19	1.45	
14	0.2	880	0.85	850	3.0	0.55	0.56	0.54	0.56	0.54	0.54	
15						0.74	1.03	0.88	0.99	0.55	0.88	
16	0.5	900	2.00	850	4.0	1.25	1.26	1.24	1.24	1.24	1.26	
17						1.00	2.65	1.25	1.75	0.35	0.55	
18	0.4	900	2.00	850	4.0	1.24	1.24	1.26	1.24	1.26	1.25	
19						2.35	0.95	0.05	1.05	1.98	1.22	
20	1.0	1000	2.50	900	8.0	1.20	1.19	1.21	1.20	1.19	1.20	
21						1.20	2.55	2.32	1.05	0.08	1.96	

[0039]

As shown in Table 1, when the diameter is 0.1 mm, the variation in carbon content according to the conventional carburizing process is approximately 2.0%, and the variation in carbon content according to the process of the invention, is 0.01%. When the diameter is 0.2 mm, the variation in carbon content according to the conventional carburizing process is approximately 1.5%, and the variation in carbon content according to the process of the invention is 0.02%. Thus, the continuous vacuum carburizing process of the invention gives good results.

[0040]

Among the tool steel wire rods, probe pins were produced from the 0.1 mm diameter steel wire made of trial product Nos. 1 to 3 equivalent to SKH51, drills were produced from the 3 mm diameter steel wire made of trial product Nos. 4 to 6 equivalent to SKH51, and dot pins were produced from the 0.2 mm diameter high-speed cobalt tool steel wire made of trial product Nos. 7 to 9. Results of their performance evaluation are shown in FIGS. 5, 6, and 7.

[0041]

The graph of FIG. 5 comparatively shows flexural strength of the probe pins produced on the experimental basis.

Trial product No. 1 was produced by drawing a rolled coil of 5.5 mm diameter with a lower carbon

content than a desired value to a wire of 0.1 mm diameter and then by increasing the carbon content of the wire to the desired value using the continuous vacuum carburizing process of the invention. Trial product No. 2 was produced by drawing the same rolled coil as trial product No. 1 in the same manner and then by carburizing it with the conventional process so as to obtain the desired carbon content. With trial product No. 2, the results of carburizing exhibited a wide variation and thus only the samples whose carbon content was within a predetermined range were used for the probe pins. Trial product No. 3 was produced by drawing a rolled coil of 5.5 mm diameter already containing the desired carbon content to a wire of 0.1 mm diameter.

[0042]

The graph of FIG. 6 comparatively shows the life of the experimentally produced drills when they were used for machining under the conditions specified in the figure.

Trial product No. 4 was produced by drawing the rolled coil of 5.5 mm diameter with the lower carbon content than the desired value to a wire of 3 mm diameter and then by carburizing the steel wire with the continuous vacuum carburizing process of the invention to the desired carbon content. Trial product No. 5 was produced by drawing the same rolled coil as trial product No. 4 in the same manner and then by

carburizing it with the conventional process to the desired carbon content. Trial product No. 6 was produced by drawing the rolled coil of 5.5 mm diameter already containing the desired carbon content to a wire of 3 mm diameter.

[0043]

The graph of FIG. 7 comparatively shows the flexural strength of the experimentally produced dot pins.

Trial product No. 7 was produced by drawing the rolled coil of 5.5 mm diameter with the lower carbon content than the desired value to a wire of 0.2 mm diameter and then by carburizing it with the continuous vacuum carburizing process of the invention to the desired carbon content. Trial product No. 8 was produced by drawing the same rolled coil as trial product No. 7 in the same manner and then by carburizing it with the conventional process to obtain the desired carbon content. With trial product No. 8, the results of carburizing exhibited a wide variation and thus only samples whose carbon content was within a predetermined range were used for the dot pins. Trial product No. 9 was produced by drawing the rolled coil of 5.5 mm diameter already containing the desired carbon content to a wire of 0.2 mm diameter.

[0044]

Among the tool steel wire rods shown in the graphs of Figs 5 to 7, trial product Nos. 1, 2, 4, 5,

7, and 8 were produced by highly efficiently drawing the steel wire of the lower carbon content than the desired carbon content and then by carburizing it, thereby obtaining the desired carbon content.

[0045]

In terms of the flexural strength of the probe pins and the dot pins as well as the cutting life of the drills shown in Figs 5 to 7, the trial products carburized after drawing by either the process of the invention or the conventional process are superior to the trial products produced from the rolled coils containing the desired carbon content as given as the comparison examples. Between the two processes, the process of the invention provides better results. This is because that the process of the invention provides excellent carburizing with less liability to generate coarse carbides.

[0046]

The continuous vacuum carburizing process of the invention was applied to nitinol wire rods composed of nickel and titanium. Carbon contents were measured at six spots after carburizing either with the process of the invention or the conventional process to evaluate variations in the carbon content. The result is shown in Table 2.

It will be seen from Table 2 that the carburizing process of the invention causes far less variation in the amounts of carbon than do the

conventional process as is the result of the steel stocks in Table 1.

[0047]

[Table 2]

No	Chemical composition of supplied wire (wt.%)			Manufacturing method		Wire diameter mm	Carburizing temperature °C	Carburizing time (min.)	Diffusion temperature °C	Diffusion time (min.)	C% after carburizing					
	C	Ti	Ni	Adjustment of carbon content	Carburizing process						1	2	3	4	5	6
1	0.01	45.0	55.0	Supplied wire are carburized	Process of Invention	0.5	950	1.00	950	3.0	2.20	2.21	2.20	2.20	2.20	2.20
2					Conventional process						0.50	0.25	0.99	3.20	2.45	1.91

[0048]

The present invention has been described with reference to the embodiments. The invention, however, is not limited solely to these specific forms, and various modifications may be made to the described, specific forms within the scope of the appended claims, or the invention may take other forms as well.

For example, although the above embodiments have been described as carburizing the steel wires steel wires, the invention is effective not only for wires with a circular cross-section but also for materials of other shapes such as a pipe shape and a strips shape as long as they have small cross sections.

[0049]

Besides, it is also possible to introduce, for instance, nitrogen gas instead of the carburizing medium in the latter half part of the first furnace core tube or the second or third furnace core tube, form a nitride layer on the surface of the carburized metal wire during it passes through the furnace core tube, and thereby produce functionally gradient material.

INDUSTRIAL APPLICABILITY

[0050]

By using tool steel of a lower carbon content than a desired amount and by carburizing it according to the invention, it is possible to manufacture thin

tool steel wire with high manufacturing efficiency, greatly reducing lead time on the tool steel wire used for dot printer pins, probe pins, drills, etc.

Also, by applying the carburizing according to the invention to stainless steel, it is possible to form uniform carburized layers near the surface with a depth accuracy which cannot be achieved by conventional carburizing processes. This results in an ultra-thin stainless steel wire whose inner section has flexibility and which has been carburized to a certain depth from the surface and has moderate rigidity. Thus, the applicability of the stainless steel wire is extended to machine parts which require corrosion resistance and wear resistance.

Alternatively, when the nitinol, an alloy of nickel, is carburized, fine carbides are separated out on the surface or in its inner sections. The alloy is applicable to curtain guide wires and the guide wires thus obtained have flexibility, moderate rigidity, and excellent operability.

BRIEF DESCRIPTION OF THE DRAWINGS

[0051]

FIG. 1 is a schematic diagram showing the manufacturing process of a tool steel wire in which the continuous vacuum carburizing apparatus according to an embodiment of the invention is applied;

FIG. 2 is a longitudinal sectional view of

the continuous vacuum carburizing apparatus of FIG. 1;

FIG. 3 is a sectional view showing the essential part of the continuous vacuum carburizing apparatus according to another embodiment of the invention;

FIG. 4A is a view showing the layout of gas inlet pipes and exhaust pipes in the continuous vacuum carburizing apparatus of FIG. 2;

FIG. 4B is a view showing a modification of the pipe layout of FIG. 4A;

FIG. 4C is a view showing another modification of the pipe layout of FIG. 4A;

FIG. 5 is a graph comparatively showing flexural strength of probe pins produced experimentally by the process of the invention and by a conventional process;

FIG. 6 is a graph comparatively showing the machining performance of drill materials produced experimentally by the process of the invention and by a conventional process; and

FIG. 7 is graph comparatively showing the flexural strength of dot pins produced experimentally by the process of the invention and by a conventional process.